THE GRAPHIC ANALYSIS OF LABOR

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IN AN effort to evaluate the effects of various factors upon the course of labor, a simple, reproducible, and relatively objective method of recording and comparing progressive changes was sought. Of the major observable events that occur during labor, i.e., force, frequency, and duration of uterine contractility, descent of the presenting fetal part and cervical effacement and dilatation, only the last-named was selected for detailed study because it seemed to parallel over-all progress best. A general mathematical expression was derived based upon the graphic portrayal of changes in dilatation of the cervix with time. The curves obtained in all normal cases studied were near-identical S curves, varying only in slope. The study is presented because of its unique simplicity and ready adaptability to the study of labor.

In a review of a half century of obstetrical literature, it is noted that numerous methods of objective study of labor have been devised and put to brief or prolonged use. Calkins and associates[3-6] used the clinical evaluation of cervical resistance (graded according to the effacement, dilatation, and softness at the onset of labor) and of "motive force" (intensity and frequency of uterine contractions) in an effort to predict the expected total duration of the first stage. A rough rule was derived. It was concluded that "more accurate observation of the resistance of the cervix (and the pelvic floor), as well as a more accurate determination of the effectiveness of the labor pains, will be necessary in order to analyze the causes for the extreme variations in the lengths of labor so commonly encountered." The frequency and duration of contractions have been studied clinically.[11] A labor was noted to be a function of the duration and number of contractions necessary for its evolution. Neither method permitted accurate evaluation en passant.

Koller and Abt[14, 15] and Abt[1] utilized a cervical dilatation-time function to demonstrate the effect of rupture of the membranes upon the course of labors. The graphs presented were not true representations of progressive change because of the nonlinear ordinate scale, the divisions of which were unequal. The divisions represented 1 to 2 fr., 5 fr., "small palm" (circa 6 cm.), "palm" (circa 8 cm.), full dilatation, delivery of the infant and of the placenta, respectively, this despite Liepman's[16] plea for standardization of cervical dilatation nomenclature. The zero of the abscissa time was taken as the time of rupture of membranes. By superimposing curves aligned at zero time it could be demonstrated grossly that dispersion of curves before and after rupture of membranes is different. Linear change was assumed and analysis was concerned with average slope and with maximum delivery time. The latter allowed but a rough measure of control in the evaluation of a labor in progress, and then only near its termination.

Apparently, the problem of the effect of amniotomy was foremost, many studies[2, 8, 9, 12, 19] having been concerned with it; and the task of establishing a "norm" for the course of labors, with which comparisons may be made, was ignored. Zimmer[21] employed much the same method as has been used in the present study, but, again, with reference to time of rupture of membranes. The curves obtained were hyperbolic, their sigmoid characteristics having been overlooked. A marked change in slope beyond 3 to 4 cm. dilatation was recognized, but alteration of the curve by dystocia or inertia was not appreciated.

Other studies involved cumbersome equipment, some more simple and thereby often less objective. Some, still under study, analyze electrical or mechanical effects of individual contractions. It is not the purpose of this discussion to evaluate these studies. It is believed however, that they may border on the frontier of obstetrical progress. This presentation is put forth nevertheless to provide a realistic tool for the study of individual labors, in progress, by obstetricians outside of university hospitals.

Methods and Materials

The patients studied were all primigravidas at term who presented themselves sufficiently early in their labors to permit adequate study. With few exceptions they all instituted labor spontaneously and despite a lack of regard for cephalopelvic relationship in selection nearly all delivered vaginally with vertex presentation. A series of cases, the first 100 of which are reported here, was accordingly studied in considerable detail. There were 29 spontaneous, 64 prophylactic low forceps and 4 midforceps deliveries. The midforceps procedures were ascribed to relative cephalopelvic disproportion, secondary inertia, transverse arrest, and fetal distress, respectively. The one cesarean section was performed because of arrested progress after prolonged trial of labor including three hours of second stage. One frank breech presentation is included; the delivery was uncomplicated. There was one multiple pregnancy in this series, the first twin delivered by prophylactic low forceps, the second by version and breech extraction because of cord presentation. All infants were liveborn. One neonatal death occurred on the first day following a precipitate labor and an uncomplicated spontaneous delivery. Death was attributed to a large subdural hematoma found on postmortem examination. There were 3 cases of primary inertia, and 7 of clinically authenticated secondary inertia. Pitocin infusion was used in attempts to induce 4 labors: for pre-eclampsia in 3 instances, and ruptured chorioamniotic membranes for a prolonged period of time at term in one. In addition Pitocin was invoked to stimulate 5 labors already in progress, but clinically thought to be slowing. Pitocin was employed, likewise, in the 10 documented cases of inertia. Episiotomy was performed almost universally except in 2 cases, one sustaining a second degree perineal laceration, the other remaining intact. Twenty-two of the patients received caudal anesthesia throughout the greater portion of their labors.

Cervical dilatation was determined by frequent rectal examinations. Although the rectal route of determining the status of the cervix has not been universally accepted as a proper method of following the course of labor, with minimal training considerable accuracy may be obtained. Where any doubt existed, particularly with very soft or very thin cervices, sterile vaginal examinations were performed. It is to be noted, parenthetically, that determinations are of greatest accuracy at the onset and the termination of dilatation (less than 3 cm. and greater than 7 cm.). Changes usually occur so rapidly in the mid-portion of the curve that greater accuracy than that associated with the oft-quoted 10 per cent error[17] is not essential. Almost all the examinations recorded were performed by one individual throughout any one labor. This was done intentionally in order to eliminate the variability of the determination of cervical dilatation due to the differences in interpretation. All readings therefore became relative. For reproducibility, it was felt that examination should be made at the peak of a contraction, particularly where there may be significant difference between the contractile and quiescent states. Dilatation was measured in centimeters for uniformity. The frequency of examinations required depended upon the progress of labor. Often half-hourly examinations were insufficient to depict accurately the slope of a precipitous labor. Usually, however, hourly or bihourly examinations sufficed amply. No attempt was made to alter the routine labor care as performed at the Sloane Hospital for Women. Thus enemas, sedation, regional and inhalation anesthesias, Pitocin infusions, etc. were administered, and amniotomy performed as indicated.

The technique, in practice, was quite simple. Square-ruled graph paper was used with 10 divisions along the ordinate to represent the cervical dilatation in centimeters; each corresponding division along the abscissa denoted time in hours. The readings as obtained were entered and joined to the preceding notation by a straight line. The slope of each line was determined readily in terms of centimeters of dilatation per hour. For example, if the cervix dilates from 2.0 to 3.5 cm. in 2 hours, the slope is $(3.5 - 2.0) \div 2 = 0.75$.

Any medication given or procedure performed, and the time of rupture of membranes was entered. Vaginal examinations were especially marked to indicate the greater accuracy of these points. The progressive changes of the rough sigmoid curve obtained were thus available for immediate study. Major variations were apparent even to the uninitiated observer. Minor deviations from the "normal" could be detected with a minimum of effort.

Results

Onset of labor is taken according to the classic definition as that time when regular uterine contractions have been established. This is found in the cases studied to be from 1.7 to 15 hours before the onset of appreciable cervical dilatation. This period has been designated as the *latent period* or *phase one* of the first stage of labor. The mean duration of this period is 7.3 hours and a few spurious readings, apparently of normal labors in all other respects, have been noted with total first phase (well documented) up to 23.2 hours. It is during this interval that the myometrial contraction becomes oriented and the cervix undergoes changes preparatory to dilatation, such as softening and effacement. There may be no significant change of the cervix noted; or, as occurred in most cases, very slow dilatation may occur. The latter progresses slowly in a linear fashion until 2 to 2.5 cm. dilatation is reached, at which time phase two is entered. *Phase two,* or the *acceleration period,* is marked by a rapid change in the slope of the cervical dilatation curve. The upswing is apparent on the graphic records. This is the period of a continuously changing and increasing rate of dilatation. *Phase three* is entered when the maximum slope is reached. This *steady period* of rapid cervical dilatation progresses in a linear fashion for a variable length of time. It is during this most important phase that the moment-to-moment effects of "interference," such as medication, anesthesia, Pitocin, etc., can be observed. This linear dilatation period extends from 3 or 3.5 to 8.5 or 9 cm. cervical dilatation. As the first stage of labor terminates, the *fourth phase* or *deceleration period* is entered. The slope of dilatation once again slows as full dilatation is reached. This period is analogous to phase two, of acceleration, in that the slope is changing. Here, however, it is diminishing from the rapid slope of phase three to the zero slope of the second stage. (Obviously no further detectable change in cervical dilatation is possible following full dilatation and retraction of the cervix).

Conclusions

The curves obtained by the simple expediency of plotting cervical dilatation against time were all quite similar in general shape, resembling sigmoid curves (Fig. 1). The main variation appeared in phase three, representing the maximal slope. Where this was steeply inclined (i.e., during rapid cervical change), the total labor tended to be short; where more flat (slower change), the labor was prolonged. The mathematical analysis of this type of curve is quite complex* and has been considerably simplified by examining the phases separately. In essence, the following general statements have been derived.

First, the slope of the latent period is flat or nearly flat, slope 0.0 to 0.86 with a mean slope of 0.35 cm. per hour, standard deviation 0.20†, and as previously noted it varies in duration from 1.7 to 15.0 hours, mean duration 7.3 hours, standard deviation 5.5. From this alone it can be seen that a diagnosis of primary inertia is in grave doubt if made solely on the basis of lack of cervical dilatation after the onset of clinically good labor within this period. The duration of this phase is apparently quite sensitive to interference, prolonged with heavy sedation, and shortened with stimulation. This latter statement is as yet a clinical impression and has not been proved statistically. The duration of this prodromal period has no apparent bearing

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*The curves resemble those first described by Gompertz in 1825,[7, 13] represented by $y = ab^{c^x}$, and applied as a growth curve in business and population problems. The modified Gompertz equation, $y = a + ab^{c^x}$, takes into account the variability of the latent phase. The complexity of this equation and the tedium of calculating the four constants for each curve make small its practical use in the present study.

In order to diminish the mathematical complexity somewhat, transformation to linear functions may be accomplished by using the method of probit analysis developed by Finney[10] for the statistical treatment of the sigmoid curve. "The probit proportion P is defined as the abscissa which corresponds to the probability P in a normal distribution with a mean 5 and variance 1."

$$P = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{y-5} e^{-\frac{1}{2}u^2} \, du.$$

The effect of this transformation from percentage to probit is to convert the normal sigmoid curve to a straight line on a linear scale of probits. This may be considered as a stretching of the percentage scale (per cent cervical dilatation) during which process the sigmoid curve becomes straightened. In essence, the probit is no more than a convenient mathematical device for solving otherwise intractable equations. Its application here is limited by the asymmetry of the curves obtained.

†Standard deviation $\sigma = \sqrt{\frac{\Sigma d^2}{n}}$.

on the future course of labor, i.e., there is no statistical correlation between the length or slope of the latent period and the remaining portion of the labor.* In consideration of the data presented, however, a latent period greater than fifteen hours is significant, although a presumptive diagnosis of primary uterine inertia cannot be made.

Second, phase two is short and variable but is very important in determining the ultimate outcome of the labor in question. It leads from the minimum slope of the latent period to the maximum slope of the third phase. A slow acceleration generally presages a lower maximum slope and therefore a prolonged total labor; a rapid change precedes a short labor. From this it follows that the onset of labor should be measured from the onset of phase two since the ensuing changes are interrelated and apparently mutually determinant. The incorporation of the antecedent time elapsed, i.e., the latent period, gives an erroneous impression of the uterine work involved and does not permit comparisons among labors. Thus a twenty-four hour labor may consist of a twenty hour latent period and a short terminal period of activity; or a latent period of eight hours may be followed by a slow to average labor of sixteen hours. Equating these two labors is obviously in error.

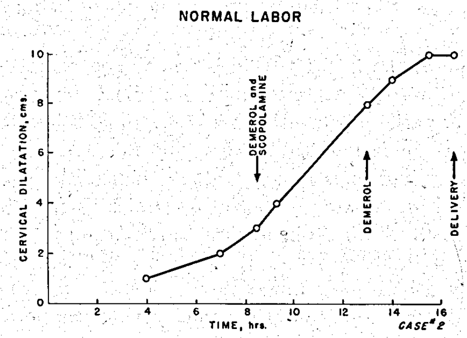

Fig. 1.—Normal labor (No. 704263). Primipara at term. Latent phase 7.0 hours, slope 0.3 cm. per hour; active phase 8.5 hours, maximum slope 1.1 cm. per hour. The sigmoid character of a normal labor is apparent.

Third, phase three, of the maximal constant slope, is inversely related to the total duration of the first stage of labor. Since the major portion of the cervical change occurs during this period (3.5 to 8.5 cm.), it is apparent that this relationship must exist. The essential linearity of progressive dilatation reflected in an unchanging slope allows for quick appraisal of deviations. It is during this portion of the first stage of labor that short-term effects of various factors may best be observed. Primary inertia, redefined, is detected by a low overall slope, cervical dilatation occurring quite slowly, but nevertheless progressing along a normal sigmoid curve (Fig. 2). Secondary inertia is reflected in a deceleration of the slope prior to that expected (i.e., before 8.5 cm.), the preceding portion of the curve having been normal (Fig. 3). The flattening of the curve prematurely is readily detected and should alert the obstetrician to seek the cause, whether cephalopelvic disproportion, inertia, cervical dystocia, excessive medication, exhaustion, or a combination of factors. This prompt detection of arrested (or arresting) labor should prove of considerable value.

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*Coefficient of correlation $r = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \cdot \Sigma y^2}}$.

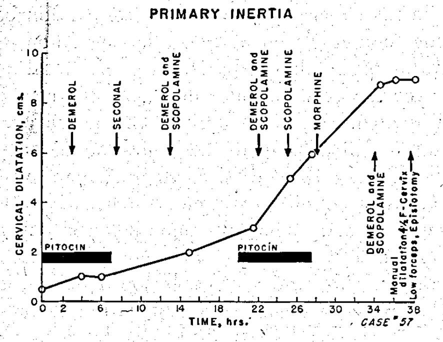

Fig. 2.—Primary inertia (No. 107138). Primipara at term, with a "primarily inert" labor. Latent phase ? 21.5 hours, slope 0.1 cm. per hour; active phase 17.0 hours, maximum slope 0.7 cm. per hour. Although the curve is sigmoid in general shape, the abscissa scale is considerably expanded.

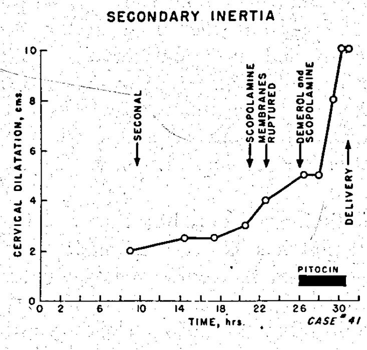

Fig. 3.—Secondary inertia (No. 124003). Primipara at term. The active phase was entered after a somewhat prolonged latent period of 17.4 hours. A maximum slope of 0.6 cm. per hour had been reached when the labor became inert, flattening the curve prematurely. Pitocin infusion subsequently re-established good labor, maximum slope 2.3 cm. per hour.

Fourth, the final phase of the first stage of labor reflects best the fetopelvic relationship in that cervical retraction about the fetal head is apparently essential in obtaining full dilatation. In simultaneous plottings of station on these graphs, it is apparent that the major portion of descent of the fetal presenting part takes place in this fourth phase of the first stage and during the second stage of labor. The descent accompanies full dilatation and retraction of the cervix, whether cause or effect is conjectural. Prolongation of the deceleration period has been observed in association with high degrees of relative cephalopelvic disproportion. Quite often the terminal phase of the first stage is short or absent (the latter probably merely unobserved). The deceleration does not closely parallel the acceleration of phase two, asserting that an independent function is active.

Fifth, the total duration of the *active phase* of cervical dilatation (phases two, three, and four, inclusive) is statistically well correlated with the slope of phase three. In contrast, there is no apparent correlation between the slope of phase three and the total duration of the first stage, nor with the total labor. Deducting the duration of the latent period from the total length of labor gives far smaller figures for the average duration of primiparous labors in this series than those usually quoted.[3, 18] The length of the active phase was noted to be from 1.8 to 9.5 hours with a mean of 4.4 hours, standard deviation 1.9. The figures for the slope of phase three ranged from 0.7 for the relatively inert labor to a maximum of 6.0 for a precipitous type of labor, with a mean of 3.7 cm. per hour, standard deviation 2.1. The difference between the mean slopes of the latent (0.35) and of the active phases (3.7) is statistically significant with probability of less than 3 per thousand.* As mentioned before, however, there is no statistical correlation between the relative slopes; nor is there a correlation between the respective durations.

Sixth, study of the second stage of labor by this method is, of course, not feasible. Here the total duration was merely noted and, as in previous studies,[4] no statistical relationship could be established between the duration of the total or any part of the first stage and the length of the second stage. The great variability of the latter depends to a considerable degree on the cephalopelvic relationship, the intensity and frequency of contractions, and patient cooperation in voluntary and involuntary expulsive efforts, as well as on the accoucheur's desires regarding instrumental delivery and episiotomy. The second stage, therefore, is not a matter for consideration here. Its management is left as a clinical art.

This has been a preliminary report based upon the analysis of our first one hundred cases. No attempt has as yet been made to assess the effects of the various factors mentioned upon the course of labor, but we expect to be able to accomplish this in the future by utilizing this method. What we have done is to redefine labor in terms of a new dimension (slope), viewing labor as a dynamic process, setting time limits solely on the basis of previous activity, and, finally, demonstrating what may be expected of a normal labor.

Summary

1. The efficacy of plotting cervical dilatation against time as a method of graphically analyzing labor is demonstrated.

2. The sigmoid characteristics of the curves thus obtained in primiparas at term are illustrated.

3. The first stage of labor is divided into four phases based on the graphic alterations noted. Their respective limits are defined.

4. Primary and secondary inertia are redefined in terms of deviation from the "normal."

5. The application of this method to the study of the effects of sedation, stimulation, anesthesia, etc., upon the course of labor is indicated.

6. The value of this method for the study of individual labors, in progress, is stressed.

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*Standard error of the difference between two means $\sigma_{\text{diff.}} = \sqrt{\sigma_1^2 + \sigma_2^2}$, where σ_1 and σ_2 are standard errors. A difference three times the standard error of difference is significant $(P = 0.003)$.